KM

METEOROLOGICAL OFFICE
131285
22 JAN 1980
C
LIBRARY

RESTRICTED CIRCULATION

This paper is not an official document; it is for information only and must not be quoted in any printed publication.

Agricultural Memorandum No. 870

Modelling the field drying of hay I. A simple model for wilting grass which ignores vertical variations in the swath

by N Thompson

1. Introduction The old saying urges us to initiate the haymaking process when the flux density of direct short-wave radiation is large, and on the whole that is good advice even if not explicit enough to define accurately the water loss from the drying crop. The problem appears fairly straightforward. The standing grass crop has, say 5 tonnes of dry matter per hectare, with water content about 400 per cent on a dry weight basis, or 20 tonnes water per hectare. To make good hay requires cutting the crop and getting rid of about 19 tonnes per hectare of moisture in a reasonably short period (say 2 - 5 days). A freely-transpiring crop on a typical summer day will lose about twice this amount. Clearly wilting grass loses water at an average rate which is substantially lower because good hay is rarely made in less than 3 days. The reason for this protracted period of drying is well-known, and is that the stomatal pathway is available only in the early stages of drying. The resistance to vapour loss becomes larger, by about two orders of magnitude for undamaged epidemis, when the stomata close, although easier pathways for vapour loss may exist for a time where there are cuts or abrasions on leaves and stems. The water content of the swath continues to decrease while the relative humidity of the ambient air remains below an equilibrium value which depends on this water content. If the relative humidity in the swath rises above that value the hay will begin to re-absorb water. Typically a swath relative humidity below 65 percent is needed to make good field-dry hay (moisture content 25 percent) and a value well below 65 percent is needed if the hay is to dry reasonably rapidly.

There are a number of simple models of grass-wilting which take no account of the vertical structure of the swath: they include ones which relate the water loss to accumulated vapour pressure deficit (eg Agena et al 1968, Spatz et al 1970) and to evaporative demand of the atmosphere (eg Firth and Leshem 1976). Bruck and van Elderen (1969) gave a very brief account of a more elaborate model which divided the swath into two layers with relative thicknesses determined by the amount of moisture in the upper part of the swath. Their treatment also considered uptake by the swath of rain. There were included a number of adjustable "constants" and perhaps because of them rather than a sound physical basis (which the model lacked) a reasonably successful simulation was achieved of water content changes in the course of a field experiment of grass wilting. van Elderen et al (1972) described more elaborate treatments of moisture increase in the swath during rain.

Processes of swath drying and rewetting are generally much more complex than assumed in these various models, and in particular show variations in the vertical which are amenable only to theoretical treatments which model the vertical structure explicitly and in detail. Nevertheless, a very simple approach which ignores completely the vertical extent of the swath can give some insight into qualitative aspects of swath drying, and give also some indication of the value of analyses which attempt to relate water loss to accumulated vapour pressure deficit or accumulated evaporative demand. Results obtained with such a model will be presented in this paper.

FH2B

2. A simple bulk model of hay drying Micrometeorological models are applicable usually only to situations where the underlying surface is essentially infinite and homogeneous in the horizontal. Haymaking practices may conflict with this requirement: for example the hay crop may be windrowed shortly before nightfall to reduce the total overnight deposition of dew, and tedding may also produce an uneven distribution of hay. The present model assumes horizontal homogeneity and, for simplicity, that the profiles of wind, temperature and humidity above the crop are logarithmic. The treatment may be developed to cope with diabatic profiles but with an increase in complexity scarcely justified by the other limitations.

The swath thickness (h) is assumed to determine the surface roughness length (z_0) according to the relation $z_0 = ah$ where $a \approx 0.1$. The wind speed at height z is given by the usual expression for the logarithmic profile

$$u(z) = 2.5\, u_* \ln(z/z_0) \qquad (1)$$

The logarithmic profiles for temperature and specific humidity are

$$T(0) - T(z) \simeq H \ln(z/z_0) / (0.4 \rho c_p u_*)$$

$$\simeq H \ln(z/z_0) / 500 u_* \qquad (2)$$

$$q(0) - q(z) = E \ln(z/z_0) / (0.4 \rho u_*)$$

$$\simeq 2E \ln(z/z_0) / u_* \qquad (3)$$

where

H = upward sensible heat flux from the swath
E = upward water vapour flux from the swath
$T(0)$ = bulk swath temperature
$q(0)$ = bulk swath specific humidity

The available energy $(R_N - G)$ is partitioned into sensible and latent heat according to the Penman - Monteith equation

$$\lambda E = \frac{\Delta'(R_N - G) + 1200 \delta q / r_a}{\Delta' + c_p(1 + r_s/r_a)/\lambda} \qquad (4)$$

where

r_s = bulk swath resistance
r_a = resistance to transfer of water vapour or heat from swath "surface" to screen height.

$$= 2.5 \ln(1.2/z_0) / u_* \qquad (5)$$

δq = specific humidity deficit at screen height

R_N and G may be calculated using empirical formulae such as those described by Thompson (1979a). Eq (1) - (5) may then be used to calculate the rate of water loss from the swath and the bulk temperature and humidity in the swath: these last are required if the simple treatment is modified to include the concept of equilibrium humidity when computing water vapour loss from the swath.

3. Applications of the model Two contrasting situations will be considered:

A: shortly after cutting, $r_s \simeq 30\,s\,m^{-1}$, h either 0.05 or 0.15m (the latter in order to investigate the effects of tedding on drying rate).

B: several hours after cutting, on a good drying day: here r_s is assumed to have risen to $3000\,s\,m^{-1}$ on closure of the stomata and sealing of most cuts and abrasions on the stems and leaves. Values for h of 0.05 and 0.15m are used.

Available energy $R_N - G$ is assumed to be $200 W m^{-2}$: the 10m wind is taken to be $3 ms^{-1}$, and screen temperature and screen specific humidity deficit 21 deg C and 6×10^{-3}. In practice the drier crop (B) will be hotter and this will be reflected in a higher screen level temperature. The difficulty of translating screen temperature

over uncut grass to temperature at the same height over a hay field suggests that a useful improvement might be made by extrapolating, the standard screen data to a height of say 20m, at which level the differences over the two surfaces are likely to be smaller. This would lead to a revised equation (5). These changes have not been incorporated in the model discussed here.

CASE A ($r_s = 30\ s\,m^{-1}$) Evaluation of Eq (4) produces values of 181 Wm^{-2} for the compact swath ($h = 0.05$ m) and 196 Wm^{-2} for the looser, deeper swath ($h = 0.15$ m). The difference of about 9 percent suggests that tedding is scarcely worthwhile in the course of this early stage of grass-wilting, except to spread the grass uniformly over the underlying surface (later when the hay becomes drier and more brittle excessive tedding may lead to significant harvesting losses caused by the difficulty of picking up small fragments of leaves fractured during tedding and settling into the stubble.

CASE B ($r_s = 3000\ s\,m^{-1}$) Most of the available energy now leaves the swath as sensible heat and errors in calculating the water vapour loss from the swath are of little consequence as far as temperature and relative humidity in the swath are concerned. Application of the simple theory shows that the more compact swath is hotter (33.6 compared to 29.8 deg C) and with lower relative humidity (29 per cent against 36 per cent). These results are not unexpected because a smooth compact swath creates less mechanical turbulence in the air above than a thicker rougher swath above which the turbulent diffusion coefficients will be larger. The same amount of heat has to be lost in either case and so the smoother swath is hotter.

The results from the second case demonstrate the limitations of the simple model, because it is well-known that tedding will speed the drying of the hay crop. The failure of the model is due to its neglect of the vertical variations of moisture content within the swath. The rate of drying is lower at the base of the swath because of the usually lower temperature there, and tedding is essential in order to bring this moister material to the upper part of the swath where it then dries much faster.

Despite this failure of the model to represent in detail the drying process it may still have applications in the rough assessment of hay-drying rate, provided account is taken of the role of equilibrium humidity in controlling the drying rate. This requires a re-derivation of the combination equation (4) using a revised resistance equation for vapour transfer from within the swath material to its surface. Thus one may write, conventionally,

$$r_a = \rho c_p (T(o) - T(z))/H \qquad (6)$$

$$= \rho\ (q(o) - q(z))/E \qquad (7)$$

The revised equation for bulk swath resistance is assumed to be

$$r_s = \rho(q_{sat}(T=T(o)).x - q(o))/E \qquad (8)$$

where $100\,x$ is the equilibrium relative humidity of the swath. Thus,

$$r_s + r_a = \rho(q_{sat}(T=T(o)).x - q(z))/E \qquad (9)$$

Now,

$$q_{sat}(T=T(o)) = \Delta'(T(o) - T(z) + q_{sat}(T=T(z)) \qquad (10)$$

where

$$\Delta' = \partial q_{sat}/\partial T \qquad (11)$$

Also,

$$\lambda E = R_N - G - \rho c_p (T(0) - T(z))/r_a \quad (12)$$

using Eq (9) and (10)

$$r_s + r_a = \rho(\Delta'(T(0) - T(z)).\varkappa + q_{sat}(T=T(z)).\varkappa - q(z))/E \quad (13)$$

Hence

$$\lambda E = R_N - G - \frac{\rho c_p}{r_a}\left(\frac{E(r_s+r_a)}{\rho\Delta'\varkappa} - \frac{q_{sat}(T=T(z)).\varkappa - q(z)}{\Delta'\varkappa}\right) \quad (14)$$

writing

$$\delta q' = q_{sat}(T=T(z)) - q(z)/\varkappa \quad (15)$$

Then,

$$\lambda E = \frac{\Delta'(R_N-G) + 1200\,\delta q'/r_a}{\Delta' + c_p(1 + r_s/r_a)/\lambda\varkappa} \quad (16)$$

This revised equation may be compared with the Penman - Monteith equation (4).

Unpublished data of Lewis - Jones (1978) suggest that for perennial ryegrass the relationship between $\varkappa$ and percentage water content on a dry weight basis is approximately

$$\varkappa = (1 - \exp(-\alpha W/100))^{1/2} \quad (17)$$

where $\alpha \simeq 2.2$. Shepherd (1958) published data in moderately good agreement with this relation but found that there was some systematic variation with swath temperature, accounted for by re-writing the last equation as

$$\varkappa = (1 - \exp(-\alpha W(1 + 0.015(T(0) - 20))/100))^{1/2} \quad (18)$$

: the correction is probably small enough to be neglected for the purposes of this simple model, which is convenient because its calculations requires the determination of $T(0)$ rather than direct use of screen temperature.

The model may also be adapted for use in situations where the swath is wetted by rain or dew. Calculation of the amount of intercepted rain is done roughly by assuming the swath intercepts half the rainfall up to 0.1 mm per unit leaf area index of the swath and then about one sixth of the rainfall thereafter, to a final maximum of 0.2 mm per unit LAI (Thompson 1979b). The duration of bulk surface wetness is obtained by application of Eq (4), putting $r_s = 0$. The amount of water absorbed into the swath material while the swath is wet will be given by a version of Eq (16) modified to account for the fact that the swath temperature now depends much more on evaporation of surface water than on exchange of water vapour between swath material and swath atmosphere (strictly the duration of surface wetness should be adjusted to take into account the amount of water re-absorbed though in many cases the correction is likely to be small). However a satisfactory first approximation for re-absorption while the swath is wet may be to use Eq (8) with r_s assumed to be the value appropriate to the drying swath and swath temperature equated to screen temperature, and $q(0)$ equal to $q_{sat}(T=T(0))$

Perhaps the major difficulty in applying models of swath drying stems from uncertainty in the value to choose for swath resistance (r_s). Use of only two values, the first when stomata are still open, and the second throughout the whole of the subsequent wilting period is almost certainly a considerable oversimplification. It is hoped that suitable data to verify this point and to test this and more elaborate models will become available in thenext two or three years from experiments at GRI.

4. Discussion and conclusions A simple model of swath drying, formalised by eq (16) and (17), has been developed. The simplicity of the treatment suggests that the model may not be able to represent very accurately the exact drying curve for a swath, but it provides a much more soundly-based estimate of the length of period from cutting to field dry hay than, for example, accumulated vapour pressure deficit or accumulated potential evaporation.

Some sample calculations using the model give at least a qualitative indication of its utility. The chosen input data are as follows:

(i) Daytime:

10m wind = 3m s^{-1}
$R_N - G$ = 200 Wm^{-2} or 100 Wm^{-2}
T (1.2) = 20 deg C
Dewpoint (screen) either 12 deg C (RH = 60 per cent)
or 15 deg C (RH = 73 per cent)

(ii) Nighttime:

10m wind = 2m s^{-1}
$R_N - G$ = $-30 Wm^{-2}$
T (1.2) = 10 deg C
RH = 100 per cent

Table 1 shows the rate of loss/gain of water from the swath, expressed as percent per hour on a dryweight basis, for a swath with 5 tonnes ha^{-1} of dry matter. r_s for the swath is assumed to be 3000 sm^{-1} (approximately one hundred times the bulk resistance of the grass when uncut and freely transpiring). The rates of loss

Table 1 Rate of water loss from swath (per cent per hour)

$R_N - G$ (Wm^{-2})	T (deg C)	Rel. Hum (%)	Swath water content (%)	Water loss % per hour
200	20	60	100	3.1
			50	2.4
			25	1.4
		73	100	2.6
			50	1.7
			25	0.9
100	20	60	100	2.2
			50	1.6
			25	0.8
		73	100	1.7
			50	1.1
			25	0.3
-30	10	100	100	0.1 (a)
			50	0.4 (a)
			25	0.8 (a)
				4.9 (b)

(a) rate of uptake of water by swath material
(b) rate of condensation of water onto swath.

for the wetter swaths are certainly less than one would expect to observe in the field and clearly the value of r_s has been set too high in their case at least. In spite of this the model is able to represent the decreasing rate of water loss as swath water content decreases and especially the low rates of loss at low available energy and higher relative humidity. A significant uptake at night by the drier swaths in conditions of high humidity is also correctly modelled. The model therefore appears to be able to represent at least qualitatively most of the important aspects of swath drying.

Any comments or suggestions on this paper should be referred to the author.

Meteorological Office Met O 8a
London Road
Bracknell
Berkshire

December 1979

References

Agena, M U, Bätjer, D and Wessels, G 1968 Wieviel Einfuhrtage stehen in nordwestdeutschen Raun fur die bergung von Winterfuther Zur Verfüngung? Meteorologische Rundschau, 21, 169.

Bruck, I G M and van Elderen, E 1969 Field drying of hay and wheat, J Agric. Eng. Res., 14, 105 - 116.

Firth, D R and Leshem Y 1976 Water loss from cut herbage in the windrow and from isolated leaves and stems. Agricultural Meteorology, 17, 261 - 269

Shepherd, W 1958 Moisture relations of hay species Austral. J Agric. Sci., 9, 437 - 445.

Spatz, G., van Eimern, J and Lawrynowicz, R 1970 Der Trocknungsverlauf von Heu im Freiland Bayerisches Landwirtsch, Jahrback 1970, 47, 446 - 464.

Thompson, N 1979a Agricultural Memorandum No 859

Thomspon, N 1979b Agricultural Memorandum No 842

van Elderen, E de Feijter, J and van Hoven, S P J H 1972 Moisture in the grass swath, J Agric Eng Res 17, 209 - 218.

RESTRICTED CIRCULATION

METEOROLOGICAL OFFICE 131284 22 JAN 1980 LIBRARY

This paper is not an official document: it is for information only and must not be quoted in any printed publication.

Agricultural Memorandum No 871

Modelling the field drying of hay II: A multi-layer swath model, and some results for a dry canopy

by N. Thompson

1. Introduction. Cut grass lying in a field forms a special type of crop canopy. Provided major simplifications are made it is possible to simulate the field drying of this grass using a suitable canopy model. A reasonably realistic simulation requires a model which is substantially more complex than, for example, that described by Thompson (1979a) for a growing crop because the simulation has to describe a process which includes not only the swath but also the transpiring stubble beneath, and in addition changes in the swath structure produced by tedding. It will be shown that fairly rigorous but straightforward treatments may be devised to represent many of the main aspects of the hay-drying process. However an outstanding problem in simulation is caused by the horizontal non-uniformity of the swath. This requires a major micrometeorological investigation in its own right, being a particularly difficult problem in advection, and although fairly advanced models using higher order closure techniques are now being applied to the simplest of the advection cases, flow across the single boundary between two different types of horizontal surfaces, there appear to have been no attempts to use such models to simulate the much more difficult aspects of advection involved in the present case. A substantial weakness therefore of the simulator of the hay-drying process described in the remainder of this paper is the neglect of the horizontal inhomogeneities in the swath.

2. A model to simulate field drying of hay.

2.1 Swath structure. The cut grass is assumed to be distributed uniformly in both horizontal and vertical width thickness SWATHI before the first tedding and TEDTHI after tedding. The swath lies on stubble of height STUBHT, with some overlap of swath and stubble. Height of the top of the swath above ground is

$$\text{HEIGHT} = \text{SWATHI} + \text{SWABOT} \quad \text{(untedded)} \qquad (1)$$

$$= \text{TEDTHI} + \text{TEDBOT} \quad \text{(tedded)} \qquad (2)$$

The model treats the vegetation in n - 1 layers of thickness HEIGHT/(n-1). Total leaf area index of the swath is CUTLAI and of the stubble is DEADLA + GRNLAI, each uniformly distributed: DEADLA refers to dead stubble and GRNLAI to living stubble. Leaf area of swath and stubble is assumed to remain constant throughout the drying process. Total leaf area index in each model layer depends on the relative thickness of swath and stubble, and their overlap, and in a single layer may include contributions from one, two or three of the components of the foliage. The contributions are calculated and held separately in an

FH2B

array ALAIRY (j,i), (j=1,3, i=1,n-1).

2.2 Initialisation of moisture status of the foliage. Surface water at the start of the simulation period is distributed according to the total leaf area index in each layer, up to a maximum of 0.2 mm per unit leaf area index (Thompson 1979a). Rainfall during the period under study is assumed to be intercepted by each layer in the way described by Thompson (1979a), preferentially from the upper layers downwards, up to the same maximum of 0.2 mm per unit LAI. The initial internal water status of the swath is specified, together with the water content of the dead stubble. Dry matter weight per unit leaf area is assumed to be the same for both swath and stubble.

2.3 Resistance to water loss from leaf tissue. Leaf stomatal resistances for the green stubble are calculated as in Thompson (1979a) for cereals, taking into account reduced stomatal opening at low light intensities. No attempt is made to modify the values to account for the effects of soil moisture deficit but this could be done by assuming that the resistance of individual parts of the stubble follows the behaviour of bulk canopies as described by Russell (1979) (see Thompson 1979b).

It is assumed in the case of the swath that the stomata remain open after cutting until closure caused either by falling light levels or when a specified fraction of the water content of the swath has been lost, whichever is the earlier. Thereafter the stomata remain closed. It is useful at this point to introduce the concept of an equilibrium humidity for the swath. Swath material kept in an atmosphere at constant relative humidity and temperature will, after a sufficiently long time, adjust its water content until in equilibrium with the environment. Unpublished data by Lewis-Jones (1978) suggest that for perennial ryegrass the relationship between percentage water content w (dry weight basis) and equilibrium relative humidity RHEQUI is approximately

$$RHEQUI = 100\,(1 - e^{-\alpha w/100})^{\frac{1}{2}} \qquad (3)$$

where $\alpha \simeq 2.2$

Shepherd (1958) published data in moderately good agreement with this relation, but found that there was some systematic variation with temperature of the swath, accounted for by re-writing Eq (3) as

$$RHEQUI = 100\left(1 - \exp\left(-\frac{\alpha w}{100}\left(1 + 0.015\,(T-20)\right)\right)\right)^{\frac{1}{2}} \qquad (4)$$

where T is in degrees C

Water is lost or gained by the swath according to whether RHEQUI is greater than or less than the relative humidity in the swath. The i^{th} layer in the foliage may include swath material and dead and living stubble and the resistance model for water vapour transfer as used by Thompson (1979a) has to be modified to take this into account. The layout of the revised model is summarised in Figure 1. Labels 1,

2 and 3 refer to swath, dead stubble and living stubble respectively. r_s and r are the layer stomatal resistances and the layer leaf boundary layer resistances, and R is the inter-layer resistance. R and r are assumed to be the same for both water vapour and sensible heat transfer. q_i is the specific humidity of the i th layer. ϵ is the potential or driving force for transfer of water vapour from within the leaf to the top of the swath. For example

$$\epsilon_1(i) = \rho\,(q_{sat}\,(T=T_o(i))\,x - q(h)) \qquad (5)$$

where

$T_o(i)$ = leaf temperature (assumed the same for all constituents in the layer)

x = RHEQUI/100 (for swath material)

The three resistance equations for transfer of water vapour from within the plant tissue in the i th layer to the free air within the layer are then

$$\rho\,(q'_i \cdot x - q_i) = E_1(i)\,(r_{s1}(i) + r_1(i)) = A\,E_1(i) \qquad (6)$$

$$\rho\,(q'_i \cdot y - q_i) = E_2(i)\,(r_{s2}(i) + r_2(i)) = B\,E_2(i) \qquad (7)$$

$$\rho\,(q'_i - q_i) = E_3(i)\,(r_{s3}(i) + r_3(i)) = C\,E_3(i) \qquad (8)$$

where

$$q'_i = q_{sat}\,(T=T_o(i))$$

y = RHEQUI/100 for the dead stubble

Also,

$$E_1(i) + E_2(i) + E_3(i) = E_i \qquad (9)$$

Eliminating $E_2(i)$ and $E_3(i)$ from Eq. (6)-(9) leads to

$$E_1(i) = (BC\,E_i - \rho q'_i\,(B - x(B+C) + Cy))/(AB + BC + CA) \qquad (10)$$

The resistance equation for transfer of water vapour from swath material to the top of the swath may be written (cf Thompson 1979a, Eq(20))

$$\rho(q'_i \cdot x - q(h)) = E_1(i)(r_{s1}(i) + r_1(i)) + R_1\sum_{p=1}^{n} E_p + \ldots + R_i\sum_{p=i}^{n} E_p \qquad (11)$$

where

$r_{s1}(i)$ = $r'_{s1}(i)$ / 2. ALAIRY (1, i)

$r_1(i)$ = $r_1'(i)$ / 2. ALAIRY (1, i)

$r'_{s1}(i)$ = leaf "stomatal" resistance per unit epidermis area

$r_1'(i)$ = leaf boundary layer resistance per unit epidermis area

$E_1(i)$ may be eliminated between Eq. (10) and (11) to give

$$\rho\left(q_i'\left(x+\left(\frac{r_{s1}(i)+r_1(i)}{AB+BC+CA}\right)(B-x(B+C)+Cy)\right)-q(h)\right)$$

$$=\frac{BCE_i}{AB+BC+CA}(r_{s1}(i)+r_1(i))+R_1\sum_{p=1}^{n}E_p+\cdots$$

or

$$\rho(q_i'\cdot m-q(h))=\cdots \qquad (12)$$

Eq. (12) may be applied in any layer which contains swath and stubble material. The corresponding equation for a layer which contains swath material only is

$$\rho(q_i'\cdot x-q(h))=E_1(r_{s1}(i)+r_1(i))+R_1\sum_{p=1}^{n}E_p+\cdots \qquad (13)$$

For a layer which includes only stubble

$$\rho\left(q_i'\left(1-\frac{(r_{s3}(i)+r_3(i))(1-y)}{B+C}\right)-q(h)\right)$$

$$=\frac{B}{B+C}E_i(r_{s3}(i)+r_3(i))+R_1\sum_{p=1}^{n}E_p+\cdots \qquad (14)$$

These last three equations may be written in the general form

$$\rho(q_i'\cdot m-q(h))=gE_i(r_{sj}(i)+r_j(i))+R_1\sum_{p=1}^{n}E_p+\cdots \qquad (15)$$

and may then be reduced to a form equivalent to Eq (21) of Thompson (1979a).

$$\rho\left(m\Delta'\Theta_i+m\,q_{sat}(T=T_h)-q(h)\right)$$

$$=E_1R_1+E_2(R_1+R_2)+\cdots+E_{i-1}(R_1+\cdots+R_{i-1})$$

$$+E_i\left(y(r_{sj}(i)+r_j(i))+\sum_{p=1}^{i}R_p\right)+E_{i+1}\sum_{p=1}^{i+1}R_p+\cdots \qquad (16)$$

where

$$\Theta_i=T_c(i)-T_h$$

The relative distributions of swath and stubble determine which of equations (12-14) are appropriate to the i th layer, and hence the values which m, g and j take in Eq. (16).

Solutions of the model are obtained using the procedures described by Thompson (1979a).

3. Some results from the model. Simulations were carried out using meteorological data from two contrasting June days, both sunny, but one cool and the other very hot. In either case the swath with an assumed leaf area index of 5 lay

over transpiring stubble (LAI=1). Figure 2 shows results from the early stages of drying of the untedded swath during the cool day, with also the changes caused by stomatal closure in the top layer. Rates of drying in the lowest layers are very small but this is of little consequence to the overall drying rate while all the layers are transpiring. A calculation for the same meteorological conditions but after a tedding which increased the swath depth by 150% showed a rate of drying only 0.5% higher than for the untedded swath. Stomatal closure in the top layer causes a temperature rise through much of the swath and increased water loss from the layers beneath, but the overall drying rate falls by 14%. At this point tedding would probably still make little difference to the overall rate of water loss from the swath.

Calculated drying rates for two recently tedded and much drier swaths in which all stomata are closed are shown in Figure 3. Rates of drying are large but this is a consequence of the exceptionally good drying conditions for which the simulation was carried out. Relative humidities near the ground surface are increased by significant transpiration from the stubble and this results in lower water losses from the lower layers, particularly the bottom layer in the swath which overlaps the stubble. Drying rate of the swath with 100% water content is twice as large at the upper surface than at the base. The equilibrium humidity of the very dry swath is about 60%, much closer to the actual relative humidity at the bottom of the swath and this is reflected by a rate of water loss there only about one quarter of that at the upper surface. Clearly it will be essential to ted the swath regularly when conditions are less than ideal so that a uniformly dry swath can be achieved in a reasonable length of time.

Attempts to run the present model for a longer period in order to simulate the effects of dewfall and rainfall and their subsequent evaporation have not yet been successful due to some shortcomings in the model: ways around these difficulties are under review.

Concluding remarks. The model even in its present form appears to provide a basis for investigation of swath microclimate and swath drying, and has provided some insight into the effects of tedding on rates of water loss from the wilting grass. Results are encouraging enough to continue the model development to the point where the present shortcomings are removed, and it can be run to simulate a complete hay-making period. It is hoped to test the utility of the complete model against field data from experiments already carried out at the Grassland Research Institute and from further ones likely to take place there in the next year or so.

Any comments or suggestions on this paper should be referred to the author.

Meteorological Office Met O 8a
London Road
Bracknell
Berkshire

December 1979

REFERENCES

Russell, G	1979	Crop evaporation, surface resistance and soil water status (submitted to Agric.Met).
Shepherd, W	1958	Moisture relations of hay species. Austral.J. Agric.Res.,9,437-445.
Thompson, N	1979a	Agricultural Memorandum No. 842
	1979b	Agricultural Memorandum No. 859

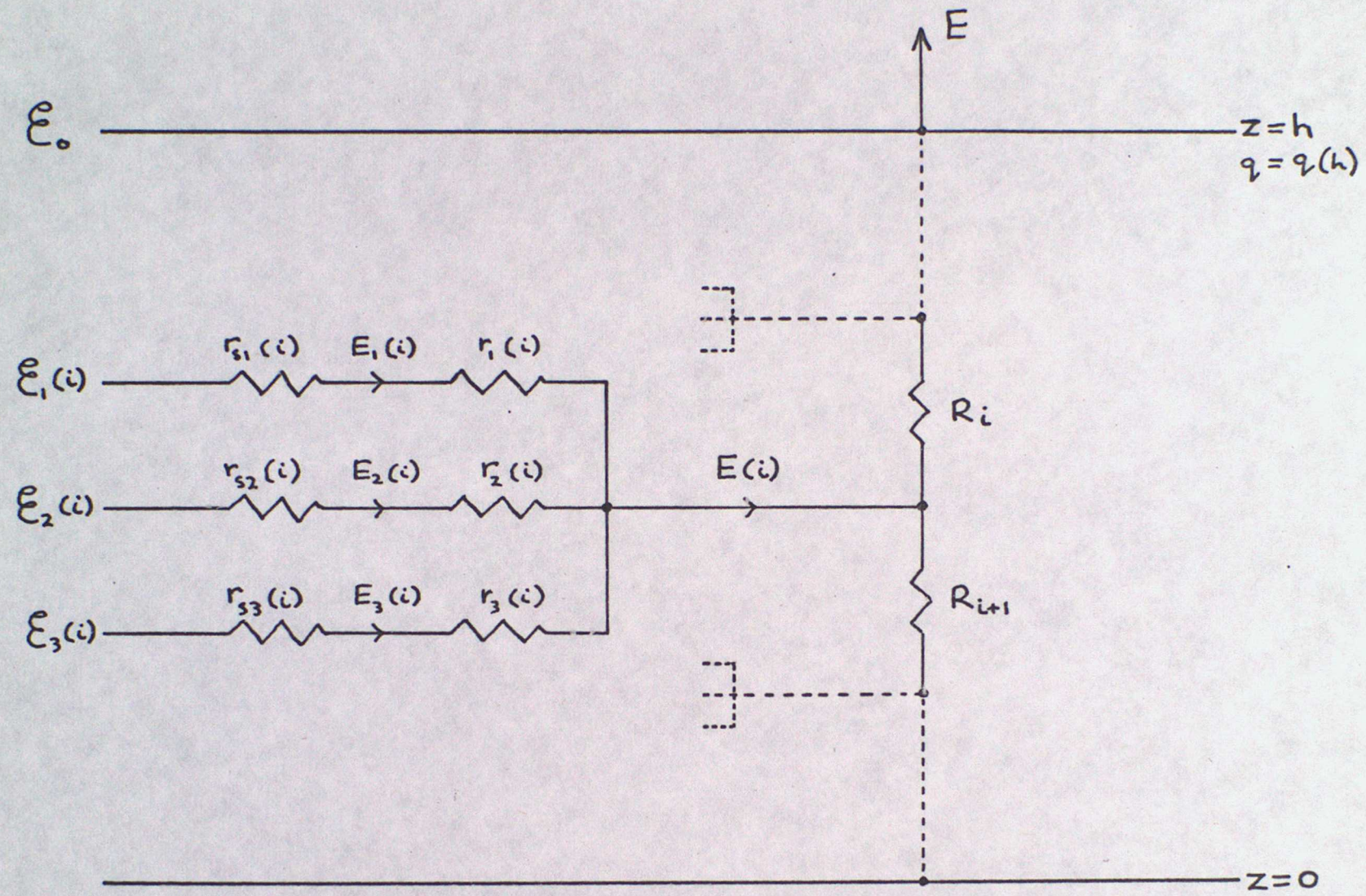

Figure 1 Resistance model for water vapour transfer in i^{th} layer

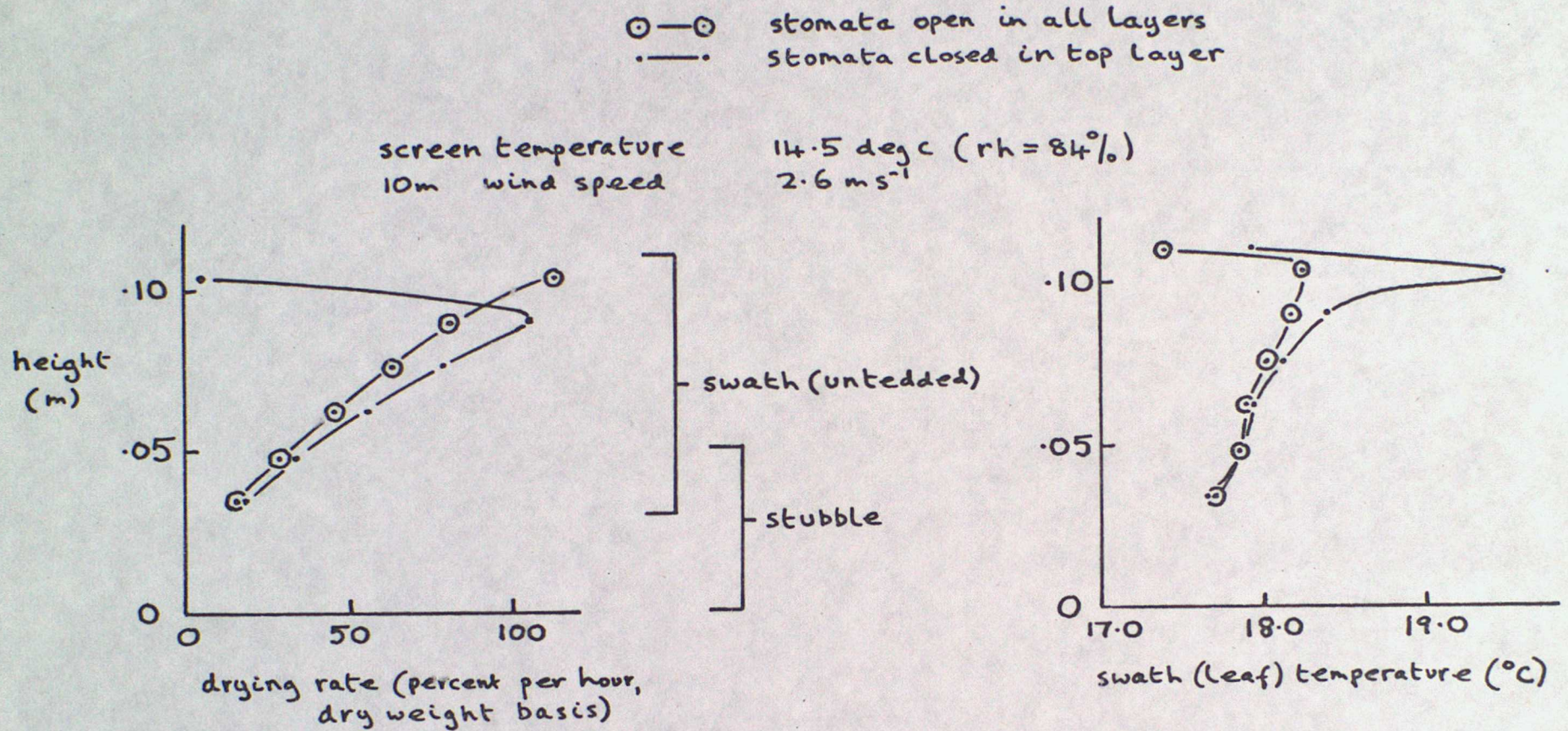

Figure 2 Calculated drying rates and swath (leaf) temperatures during the early stages of drying. Simulation is for a cool but sunny day in early June, around midday.

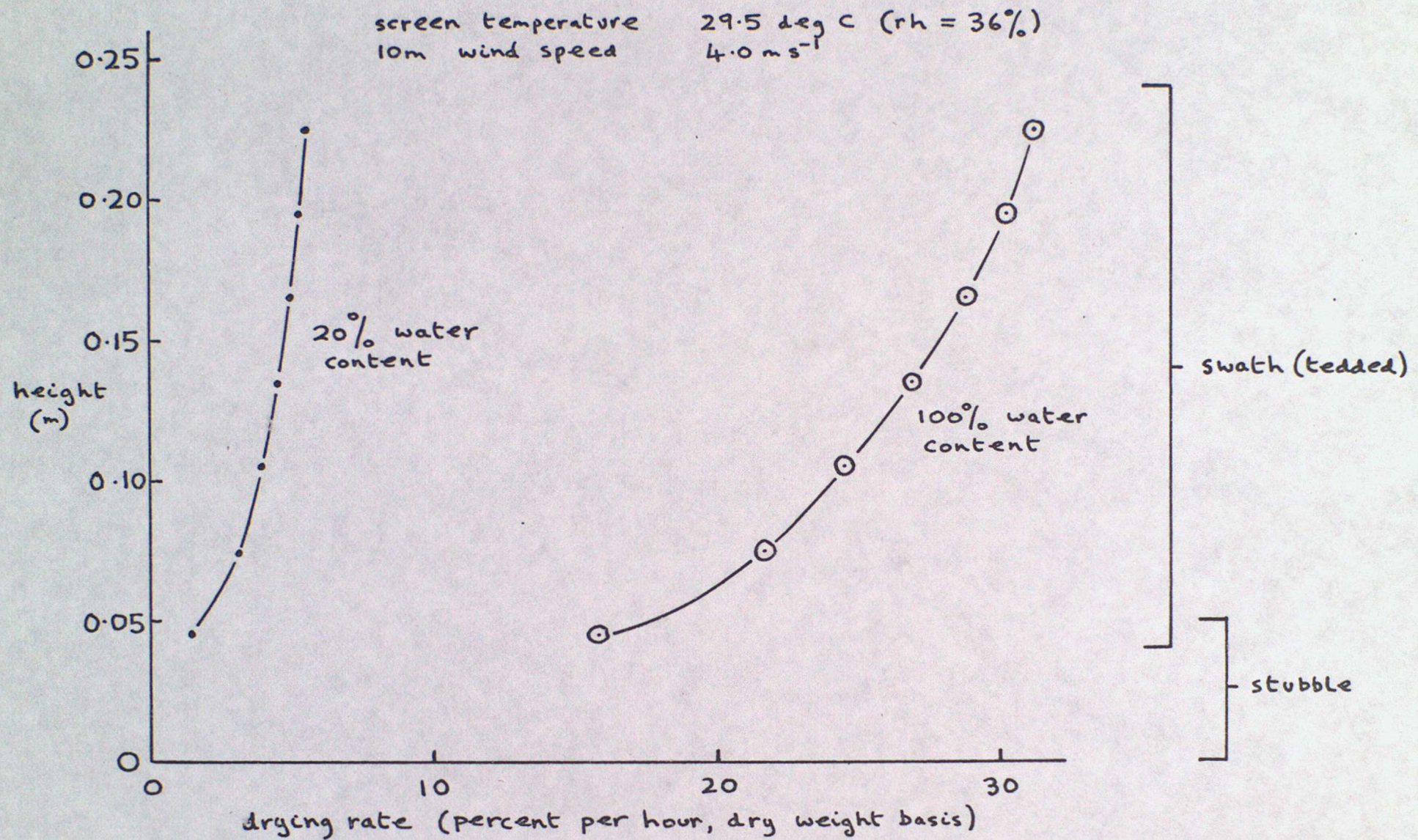

Figure 3 Calculated drying rates at 1500 Z on an exceptionally good drying day in June